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Software Package for Bio-Signal Analysis

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Abstract— **We have developed a Matlab™based software package for bio-signal analysis. The software is based on modular design and can thus be easily adapted to fit on analysis of various kind of time variant or event-related bio-signals. Currently analysis programs for event-related potentials (ERP), heart-rate variability (HRV), galvanic skin responses (GSR) and quantitative EEG (qEEG) are implemented. A tool for time varying spectral analysis of bio-signals is currently under construction. By combining different analysis tools it is possible to build analyzing procedures based on the software not only for simple sense or attention related tasks but also e.g. for responses measured during complicated psychological tests.**

Keywords— **Bio-Signals, Matlab**

I. Introduction

The notion bio-signal can be used to cover all time varying quantities which can be measured from human body. Such signals are e.g. electromagnetic signals caused by the activation of nerve cells in the central nervous system (EEG) or by activation of muscle cells during contraction (ECG, EMG). The various bio-signals are one of the main tools for examining of physiology and health of human body. For instance the heart-rate variability (HRV) is a widely used quantitative marker of autonomic nervous system activity.

Other types of bio-signals are e.g. event-related potentials (ERP), which are short transient type waveforms correlated with some physical stimulus. The properties, latency and amplitude, of ERPs are shown to be depended on internal factors related to the cognitive state of person studied [1]. With these internal factors are meant e.g. level of motivation or tiredness.

To be able effectively analyze e.g. the effects of heavy mental work load it is necessary to combine the information of different bio-signals. As there seemed to be no appropriate software for this kind of task we have developed a Matlab™ based software package for combined analysis of different bio-signals. The package consists analysis programs for galvanic skin responses (GSR), evoked potentials (ERP), heart rate variability (HRV) and for EEG. The fundamental idea has been to develop independent modules which can then be combined to suite specific measurement paradigm. This way the package can also be easily extended to analysis of other bio-signals.

Other main guideline in the developing of the software has been the ease of use without loosing too much ability to control different parameters of analysis methods. To reach this goal we have made graphical user interfaces for all analysis tools and concentrated on the layout of the report sheets that the tools generate. In Figs. (2, 4) are shown some examples of graphical user interfaces of the software and in the Fig. 3 is an example of report sheet produced by HRV analysis tool.

The properties of the developed software and the theoretic basis of implemented analysis methods are briefly described in the following sections.

II. Input data format

The input data format of the software package was selected to be the format of NeuroScan™ continuous data files (CNT-files). The selection was obvious as both Department of Clinical Neurophysiology of Kuopio University Hospital and Brain@Work Laboratory of Finnish Institute of Occupational health use NeuroScan based measurement systems. Other benefits of the CNT-files are that all information about measurements, stimuli and responses are available in one file. As a result our software has full reading support for CNT-files, for older Braintronics and newer Synamps amplifiers. There is also some support for event files generated by Stim™.

III. GSR analysis

The galvanic skin response (GSR) is a simple, useful and reproducible method of capturing the autonomic nerve response as a parameter of the sweat gland function [2]. Physically GSR is a change in the electrical properties of the skin in response to different kinds of stimuli. Any stimulus capable of an arousal effect can evoke the response and the amplitude of the response is more dependent on the surprise effect of the stimulus than on the physical stimulus strength. In measurements changes in the voltage measured from the surface of the skin are recorded. In history GSR is also known as, or closely related to, the sympathetic skin response (SSR) and skin conductance response (SCR).

GSR amplitudes vary substantially, depending on the experimental conditions. The waveshape is usually biphasic or triphasic and lasts several seconds. For an auditory stimuli, delivered to both ears, typical amplitude is (2.8 ± 1.2) mV measured from the palm [3].

Normally reproduced within-subject GSRs have common features in waveshapes. Amplitudes tend to habituate, latencies might increase slightly and waveshapes remain fairly unaltered in repetitions. The decrease in amplitudes and increase in latencies is affected by the weakening of the surprise effect of stimulation and by the weakening of alertness of the subject during the experiment.

To study the differences of the autonomic nervous system function between healthy subjects and patients in acute psychosis [4] we needed some quantitative measures for GSR responses. Thus we developed a new principal component analysis (PCA) based method for analyzing

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Abstract

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successive GSRs. The method is implemented in the software package and is described in more detail in [5]. The steps of the method are

1. The measured GSRs, z_j, are normalized, in order to make PCA sensitive to waveshapes. The data correlation matrix $R_z \approx \frac{1}{N}\Sigma_{j=1}^{N} z_j z_j^T$ is then calculated for normalized measures.
2. The eigenvalues λ and corresponding eigenvectors Ψ from the ordinary eigenvalue problem $R_z\Psi = \lambda\Psi$ are solved.
3. Similarity of waveforms z_j is revealed from the eigenvalues λ. Information about single responses is obtained by performing linear regression with eigenvectors Ψ as basis functions.

IV. Single trial ERPs

Event related potentials (ERPs) have been widely used for studying brain activity associated with higher mental functions. They are caused by the electrical activity of the central nervous system as a response to a cognitive meaningful stimulation of the sensor system. The potentials are usually measured from outer layer, scalp, of the human head. The measured potential is then superposition of all electrical activity that is originated in head. Thus one of the fundamental problems in the analysis of evoked potentials is to extract information about the potential from measurements that contain also on-going background EEG.

The most common method of primary analysis of the parameters of ERPs is to take average over the time-locked single trial measurements. The implicit assumption in the averaging is that the event-related brain signal occur at about the same time after the stimulus on each trial, while the background EEG have random or no relation to the stimulus. However, it has been evident for few decades that in many cases this assumption of constant timing is not valid [6]. Nor is the other implicit assumption, of the same shape and same degree of present on every trial [7]. Instead it has become evident that the observation of the variation of the parameters of the ERPs permits the dynamical assessment of the changes in the cognitive state of human.

One possibility to estimate single trial ERPs is to use the so-called regularized least squares method. The basic idea is to apply additional information about the evoked potentials to the estimation. This information can be concerned with the assumed smoothness of the evoked potentials or some limits may be used for the possible locations of the peaks in the potentials. The method has been used in [8] in the case of single channel measurements. The main benefit of the method is its easy implementation for different kinds of data.

The evoked potential measurements are usually performed with multiple electrodes. This means that also spatial information is gathered in the measurements. The spatial correlation of the multi channel measurements can also be taken into account in our regularization based approach. The approach is briefly introduced in [9] and in more details in [10].

The subspace regularization based method used in the software can be summarized as follows:

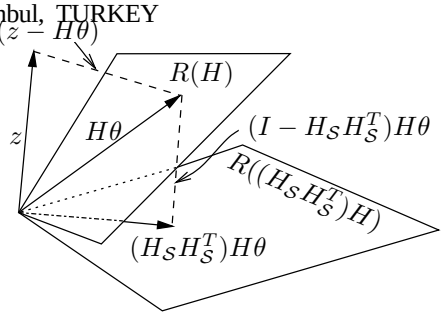

Fig. 1. A graphical interpretation of the subspace regularization method.

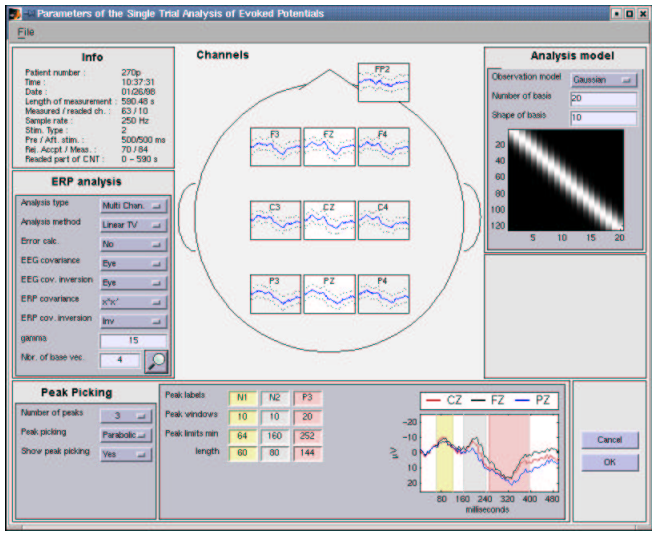

Fig. 2. One of the graphical user interfaces related to ERP analysis.

1. The linear model is used for the ERP measurements. This means that the measured signal is modeled as superposition of the ERP and the background EEG. The background EEG can be thought to represent the measurement error in the equation.
2. Furthermore ERPs are modeled as a combination of some generic basis functions e.g. Gaussian shaped humps. The solution will be in the subspace, $R(H)$ in the terms of the Fig. 1 spanned by the basis vectors.
3. The solution is then regularized to the direction of the common properties of the all measured ERPs i.e. to the subspace $R((H_S H_S^T)H)$ spanned by the eigenvectors corresponding the few largest eigenvalues of the data correlation matrix. The final solution is marked as $H\theta$ in the figure. The method can be expressed in the form of the following matrix equation.

$$\hat{\theta}_S = (H^T H + \alpha^2 H^T (I - H_S H_S^T)H)^{-1} H^T z \qquad (1)$$

In addition to single trial analysis of ERPs also traditional averaging method is implemented in the software. In the Fig. 2 are shown a screen shot of one of the graphical user interfaces related to ERP analysis tool.

V. HRV analysis

The oscillation in the interval between consecutive heart-beats (RR intervals) is called heart rate variability

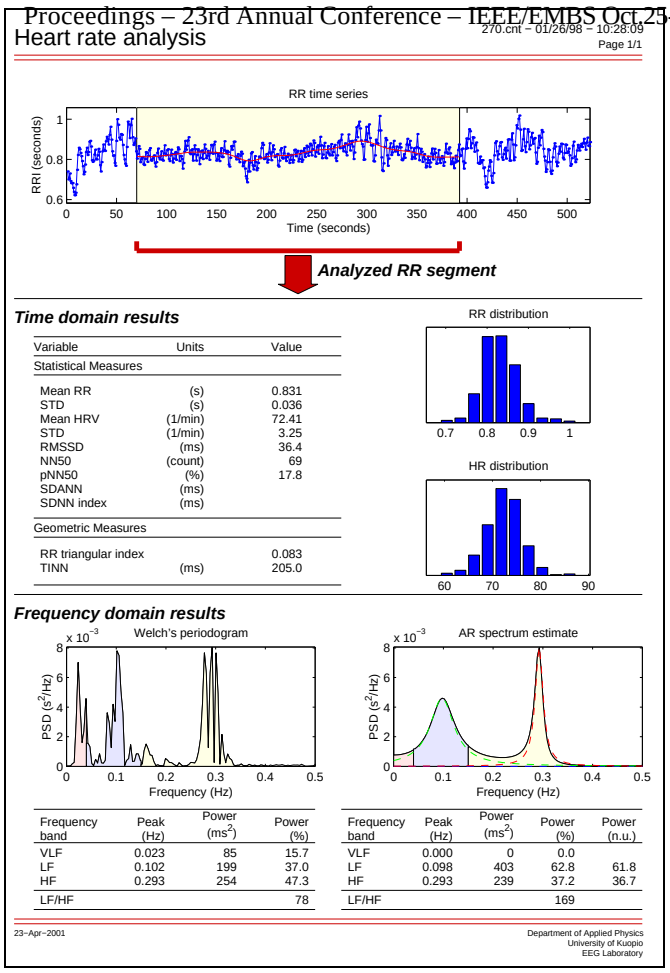

Fig. 3. Report sheet generated by HRV analysis tool.

(HRV) [11]. This phenomenon is a result of continuous alternation of the autonomic neural regulation of the heart i.e. the variation of the balance between symphatetic and parasymphatetic neural activity. HRV is widely used as quantitative marker of autonomic nervous system activity.

The base of the HRV analysis is the ECG recording of which the QRS complexes are determined. The time elapsing between consecutive heart-beats is usually measured as the time between two R peaks. The obtained RR time series is used in HRV analysis. Our software is capable to determine QRS complexes from raw ECG data. The approach for QRS detection is based on the method presented in [12].

Both time and frequency domain methods are used in HRV analysis. The developed software is capable to calculate all commonly used [11] parameters. In Fig. 3 is shown an example of report sheet generated by HRV analysis tool. With the graphical user interface it is possible to select the part of the RR data to which the analysis is applied, apply trend removal to the RR series and adjust the parameters of frequency domain methods. The trend removal is based on the fitting of the first or second order polynomial to the data or more efective regularization based smoothness priors method described in [13].

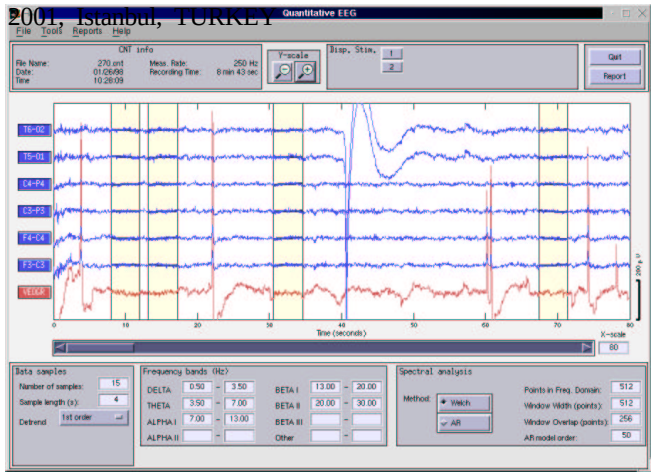

Fig. 4. User interface of quantitative EEG analysis tool

VI. qEEG analysis

The term quantitative EEG is used in contrast to qualitative EEG, in which the properties of the EEG are inspected purely visually. In quantitative analysis some measures are used to describe the EEG. Thus the term qEEG covers wide range of different methods. However most commonly the measures are based on spectral properties of the measured signal. In the software we are focused to the frequency domain measures of EEG.

The spectral content of measured EEG can be quantified with various parameters obtained from the power spectral density (PSD) estimation. PSD can be calculated by either non-parametric (e.g. methods based on FFT) or parametric (e.g. methods based on autoregressive moving average time series modelling) methods. The software calculates commonly used parameters from either Welch's periodogram or AR based PSD estimation. In Fig. 4 is shown the graphical user interface of qEEG analysis tool.

Traditionally quantitative EEG analysis is based on assumption that the sample for which the PSD is obtained is at least nearly stationary. However, sometimes the interest is in tracking of the nonstationary properties of EEG. This necessitates time-varying spectral estimation. Analysis tools for time-varying EEG analysis are currently under construction and will be included in the software package in the future.

VII. Discussion

A Matlab based software package for bio-signal analysis has been developed. The main advantages of the package is its ability to combine analysis of different bio-signals and its ease of its use. At the moment analysis tools for GSR, ERP, HRV and qEEG data has been implemented to software package and a tool for time varying spectral analysis of EEG data is under construction. Developing of new analysis tools is easy as the software is based on modular design.

With the software it is possible to build analysis procedures for complicated test designs for example for psychological tests, suchs as Wisconsin Card Sorting test. Tracking bio-signals related to special events in the test is then

easy for example examine GSR responses related to first wrong answers after strategy change in the Wisconsing Card Sorting test or search for ERP responses related to card processing.

For more information see `http://venda.uku.fi/research/biosignal/`.

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